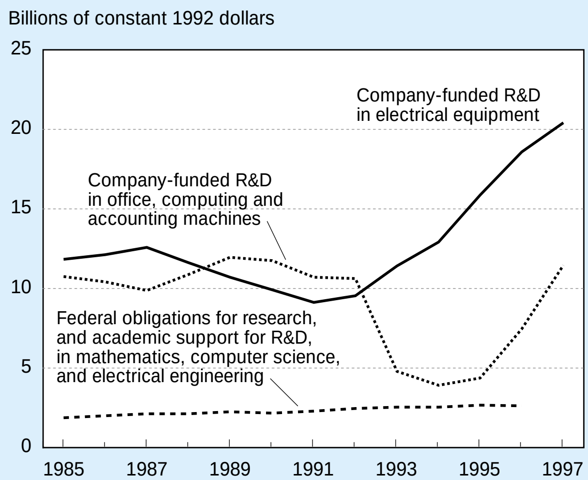
Figure 2-23.
R&D associated primarily with mathematics, computer science, and communication and electrical equipment (excluding DOD-supported development of military equipment)



See appendix table 2-51. *Science & Engineering Indicators – 2000*

close to $10 billion (in constant 1992 dollars) throughout 1985–92, after which it doubled to more than $20 billion by 1997. The second-largest category in 1997—company-funded R&D in office, computing and accounting machines—remained at or above $10 billion between 1985 and 1992 as well. It then fell sharply in 1993 to below $5 billion but recovered between 1995 and 1997; by 1997 it represented more than $11 billion in R&D. The third-largest category, Federal obligations for research in mathematics and computer science, grew from $745 million in 1985 to nearly $1.5 billion in 1996. Federal obligations for research in electrical engineering (not Federally funded) declined from $813 million to $601 million over the same period. Three small academic categories—R&D in mathematics, computer science, and electrical engineering—each nearly doubled in real terms between 1985 and 1996.

Inter-Sector and Intra-Sector Domestic Partnerships and Alliances

In the performance of R&D, organizations can collaborate, either within the same sector (e.g., a partnership between firms) or between sectors (e.g., a partnership between a firm and the Federal Government). Decisions by organizations to form these partnerships are based on economic considerations, legal and cultural frameworks, scientific and technological conditions, and policy environments.

Economic Considerations Underlying R&D Partnerships

Collaboration allows individual partners to leverage their resources, reducing costs and risks and enabling research ventures that might not have been undertaken otherwise. In the case of intra-sector collaboration, the underlying theme is that more can be accomplished at lower cost when resources are pooled, especially if organizations can complement each other in terms of expertise and/or research facilities. For private companies, another advantage of partnerships is that they reduce (or eliminate) competition between the allied companies, which may thereby enjoy higher profits once their jointly developed product is marketed.

With regard to university-industry alliances, companies can benefit from the extensive research infrastructure (including the students), as well as the store of basic scientific knowledge, that exists at universities—which those firms would not be able afford on their own.[30] Universities, on the other hand, benefit from alliances with firms by being better able to channel academic research toward practical applications" (Jankowski 1999).

In the case of collaboration between Federal laboratories and industry—in the form of Cooperative Research and Development Agreements (CRADAs)—a wide range of economic benefits to both parties have been noted. The main reason for the creation of CRADAs was that industry would benefit from increased access to government scientists, research facilities, and the technology they developed. Government, in turn, would benefit from a reduction in the costs of items it needs to carry out its objectives (Lesko and Irish 1995, 67). Both would benefit from technology transfer, and Federal R&D in national labs would be more useful to U.S. industry. Some analysts have argued as well that Congress created CRADAs[31] to simplify negotiations between the Federal Government and industry in the process of technology transfer, by making the process exempt from Federal Acquisition Regulation (FAR) requirements.

With regard to collaboration between academia and the Federal Government, little exists in the strict sense of employees from both working together, side-by-side, on R&D projects. On the other hand, collaboration in a broad sense is quite extensive in that academia receives research grants to perform "targeted research."[32] (See "Federal Support to Academia.") Some of this research is designed to meet Fed-

[30]On the topic of firms benefiting from the tacit knowledge of universities, Prabhu (1997)—citing earlier work by Tyler and Steensma (1995)—suggests, "The greater the tacitness of technology (hard to document in writing, residing in individuals, systems and processes of the firm, and difficult to transfer through market mechanisms), and the greater the complexity of technology (variety and diversity of technologies that must be incorporated into the development process), the more likely it is that executives will consider technological collaboration a mode of technology development."

[31]See the next section on the legal reasons for partnerships and alliances.

[32]Targeted research as a policy goal is discussed in U.S. Congress, House Committee on Science (1998).

eral needs, in cases in which the Federal Government does not have the physical or human resources to perform the research itself. In other cases, the Federal Government may support academic research (or research in other sectors) for the sake of creating a "public good" that would be expected to provide economic benefits to society. As many people know, one of the public goods that arose from this kind of collaborative effort is the Internet, which originated from a project funded by the Defense Advanced Research Projects Agency (DARPA) and then greatly advanced through NSF funding to universities.

Finally, international competition adds two additional considerations. First, Federal-industry partnerships and other types of partnerships in the performance of R&D in the United States may be desirable as a means of competing adequately against similar partnerships carried out in other nations. Second, the United States may choose to enter into international projects with the idea that, just like firms, nations may be able to pool resources that collectively enhance their R&D capabilities.

Federal Technology Transfer Programs

The term "technology transfer" can cover a wide spectrum of activities, from informal exchanges of ideas between visiting researchers to contractually structured research collaboration involving the joint use of facilities and equipment. Only since the late 1980s, however, has technology transfer become an important mission component of most Federal labs. Some agencies, however, have long shared their research with the private sector (e.g., USDA's Agricultural Research Experiment Stations and NASA's civilian aeronautics programs), and several laws passed in the early 1980s encouraged such sharing—notably, the Stevenson-Wydler Technology Innovation Act of 1980. (See sidebar, "Principal Federal Legislation Related to Cooperative Technology Programs.")

The emphasis, in the past decade, on technology transfer stems from practical considerations: Industry was interested in such programs, Federal money was available, and government defense labs were amenable to such activities as an alternative to their declining defense work (OTA 1995). Moreover, technology transfer was regarded as a means of addressing Federal concerns about U.S. industrial strength and world competitiveness. Another reason was that the Federal Technology Transfer Act (FTTA) of 1986 authorized government-owned and -operated laboratories to enter into CRADAs with private industry. Only after the 1989 passage of the National Competitiveness Technology Transfer Act (NCTTA), however, could contractor-operated labs (including DOE's FFRDCs) also enter into CRADAs. According to most available indicators, Federal efforts to facilitate private-sector commercialization of Federal technology have made considerable progress since 1987.

Four measures of the extent of Federal technology commercialization efforts and Federal-industry collaboration between 1987 and 1998 can be described as follows:

Principal Federal Legislation Related to Cooperative Technology Programs

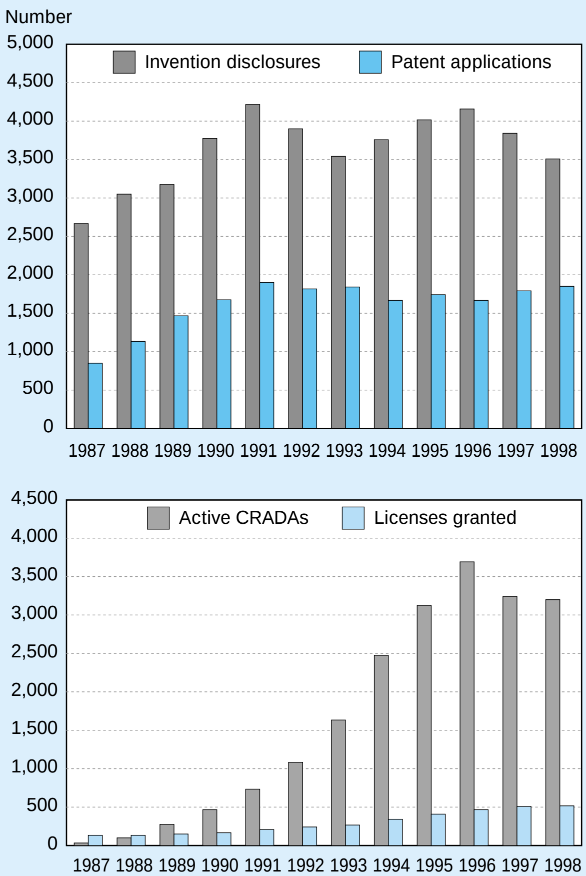
Since 1980, a series of laws have been enacted to promote Federal–civilian partnerships and to facilitate the transfer of technology between sectors. Among the most notable pieces of legislation have been the following:

- **Stevenson-Wydler Technology Innovation Act (1980).** Required Federal laboratories to facilitate the transfer of Federally owned and originated technology to state and local governments and to the private sector.
- **Bayh-Dole University and Small Business Patent Act (1980).** Permitted government grantees and contractors to retain title to Federally funded inventions and encouraged universities to license inventions to industry. The Act is designed to foster interactions between academia and the business community.
- **Small Business Innovation Development Act (1982).** Established the Small Business Innovation Research (SBIR) Program within the major Federal R&D agencies to increase government funding of research with commercialization potential within small, high-technology companies.
- **National Cooperative Research Act (1984).** Encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The Act was amended in 1993 by the National Cooperative Research and Production Act, which let companies collaborate on production as well as research activities.
- **Federal Technology Transfer Act (1986)**. Amended the Stevenson-Wydler Technology Innovation Act to authorize CRADAs between Federal laboratories and other entities, including state agencies.
- **Omnibus Trade and Competitiveness Act (1988).** Established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The Act created the Advanced Technology Program and the Manufacturing Technology Centers within NIST to help U.S. companies become more competitive.
- **National Competitiveness Technology Transfer Act (1989)**. Amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.
- **National Cooperative Research and Production Act (1993)**. Relaxed restrictions on cooperative production activities, enabling research joint venture (RJV) participants to work together in the application of technologies they jointly acquire.

- ♦ **CRADAs** grew in number geometrically, from 34 in 1987 to 3,688 in 1996—an average growth rate of more than 68 percent per year. Between 1996 and 1997, however, not only did the growth cease, the number of active CRADAs declined to 3,239. This number decreased slightly in 1998, to 3,201. (See figure 2-24.)

- ♦ **Invention disclosures** arising out of CRADAs increased rapidly at first, from 2,662 in 1987 to 4,213 in 1991(a 58 percent increase in only four years). Over the succeeding seven years (to 1998), however, that level was not reached again; the largest number was 4,153 in 1996. On the other hand, there is no apparent trend in the annual numbers of invention disclosures since 1991; those levels seem to be random, averaging 3,815 and remaining above 3,500 each year. (See figure 2-24.)

Figure 2-24.
Federal technology transfer indicators



CRADA = cooperative research and development agreement.

NOTE: Does not include CRADAs entered into by NASA.

See appendix table 2-60. *Science & Engineering Indicators – 2000*

- ♦ **Patent applications** have had a similar history. They rose in number from 848 in 1987 to a high of precisely 1,900 in 1991(a 124 percent increase). After 1991, patent applications averaged 1,765, with no apparent trend.

- ♦ **Licenses** granted rose in number steadily between 1987 and 1998, from 128 to 510.

Differences in Motivations and Goals of CRADA Participants

Studies have indicated that although partnerships between sectors offer economic and scientific benefits to the parties involved, those partnerships may be constrained by cultural differences between sectors. Some observers have argued that industrial scientists and engineers tend to place much greater emphasis than their government colleagues on profitability, international competitiveness, and turnaround time. Conversely, government scientists and engineers tend to have longer-range and more idealistic perspectives. For example, Lesko and Irish (1995) describe the Federal defense employee's "traditional view" as one in which "the primary mission…is to develop, produce, enhance, and support the military systems that provide a warfighting capability for the U.S. that is second to none" (Lesko and Irish 1995, 33–34).

Rogers et al. (1998) surveyed participants in CRADA partnerships at Los Alamos National Laboratory. They found that, according to private companies in these partnerships, the top five objectives of CRADAs were (in descending order of importance) to obtain new technology/information/patents, to save money in developing a process/product, to save costs, to improve research ability within the company, and to obtain a new product. In contrast, the top five objectives according to Federal R&D laboratory partners were to improve the research ability of the Federal R&D laboratory, such as adding capabilities; to obtain new funding; to obtain technology/information/patents; to gain credibility/prestige/employee satisfaction; and to develop or gain access to new facilities/tools. According to Rogers et al., such differences in orientation have been a major obstacle to further increases in the number of CRADAs. Rogers et al. conclude, "Since 1994, Federal funding for establishing new CRADAs has almost disappeared, mainly due to partisan differences about the role of the Federal Government in its relations with private companies" (Rogers et al. 1998, 87).

On the other hand, Lesko and Irish (1995) are more optimistic about the future ability of scientists and engineers from these different cultures to get along:

> Significant differences in the perspectives of government and industry can and do impede progress in cooperative ventures. As both sides realize that they need each other's perspectives and combined resources to survive global competition and effectively manage shrinking resources, their goals and procedures will change toward becoming more and more cooperative. Good communications can be a key to identifying, understanding, and overcoming culturally derived barriers to this process (Lesko and Irish 1995, 29).

Scientific and Technological Conditions Underlying R&D Partnerships

The complexity and interdisciplinary nature of R&D has continued to increase in recent years, as discoveries in one area of science or engineering (e.g., modular robotics systems) have had bearing on other areas (e.g., space exploration). As the scope of R&D on any topic expands, researchers from individual institutions may find themselves less able to approach the topic as broadly as they think they should; they may therefore search for collaborators who can complement their knowledge or research facilities. For example, academic researchers increasingly have sought to leverage resources and talents in the conduct of R&D. Not only does such an approach offer opportunities for alternative funding, such partnership provides an essential means for undertaking work that is becoming ever more complex and multidisciplinary (Jankowski 1999).

At the same time that scientific and engineering developments are increasing the need for—and the benefits of—R&D partnerships and alliances, advances in communication equipment and software are creating new tools that make such collaborative efforts much easier. Hazlett and Carayannis (1998) describe recent developments in "virtual teams"—especially between industry and academia—whereby communication, data acquisition, data sharing, and document sharing can all take place virtually among individuals in distant organizations. In effect, the operational costs of collaborating have been reduced enormously, thereby encouraging increased collaboration among researchers of the same or similar topics.

Current research on expanding Internet capabilities offers even more powerful tools for collaborative efforts. DOE and NSF have been sponsoring research that has been moving scientists and engineers closer to having the ability to collaborate in virtual laboratories or conference rooms through "telepresence." That is, researchers at remote physical locations interact with one another in a virtual, three-dimensional environment, experiencing each other's artificial presence as though everyone were in the same room. Such capabilities will undoubtedly enhance collaboration potential.[33]

Industrial R&D Consortia

In the early 1980s, increasing international competition and the resulting erosion in U.S. technological leadership led legislators and policymakers to conclude that existing U.S. antitrust laws and penalties were too restrictive and could be impeding the ability of U.S. companies to compete in the global marketplace. U.S. companies were at a disadvantage relative to their foreign counterparts because an outdated antitrust environment—designed to preserve domestic competition—prohibited them from collaborating on most activities, including R&D.

Restrictions on multi-firm cooperative research relationships were lifted with the passage of NCRA in 1984. This law was enacted to encourage U.S. firms to collaborate on generic, precompetitive research. To gain protection from antitrust litigation, NCRA requires firms engaging in RJVs to register them with DOJ.[34] In 1993, Congress again relaxed restrictions—this time on cooperative production activities—by passing the National Cooperative Research and Production Act, which enables participants to work together to apply technologies developed by their RJVs.

The advantages of RJVs over individual firms conducting R&D on their own have been identified as follows:[35]

- Through RJVs, companies have "the ability to pool research resources in order to achieve a critical minimum mass and pursue more and larger research projects than any single company could afford."
- RJVs can exploit synergies from the complementary research strengths of their members, creating a whole greater than the sum of its parts.
- RJVs are expected to be in a better position than any single firm to maintain the necessary continuity of effort for long-term research projects.
- RJVs pool risk both in terms of a larger number of participants in each research project and a larger number of projects.
- RJVs can reduce duplication of effort among member firms by concentrating larger resources on projects of common interest.
- RJVs can attract supplemental support from external sources, including the government, by increasing the visibility of essential industrial research projects.
- RJVs can create new investment options in technologies that are out of the reach of individual member firms because of high resource commitment required, high uncertainty, insufficient appropriability of the research outcome, inadequacy of existing capabilities, and so forth.

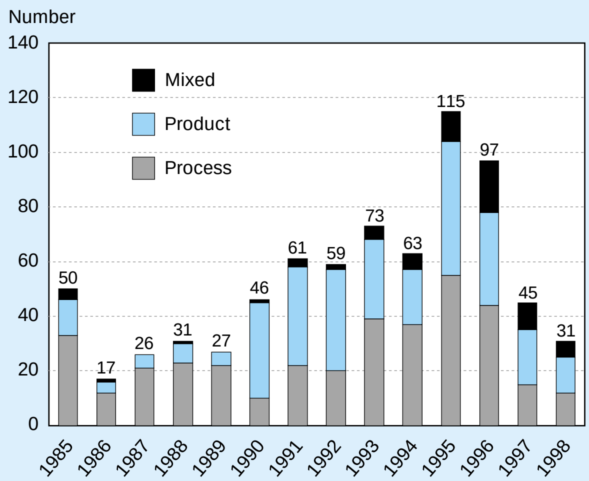
By the end of 1998, 741 RJVs had been registered; organizations such as Sematech have helped U.S. industries regain leadership in global markets for high-tech products such as semiconductors. On the other hand, by 1998 the number of new RJV filings per year had fallen sharply to 31, after reaching a peak of 115 in 1995 (Link 1999). (See figure 2-25.)

[33]See Smith and Van Rosendale (1998), Larson (1998), and chapter 9 of this report.

[34]According to NCRA, an RJV is "any group of activities, including attempting to make, making, or performing a contract, by two or more persons for the purpose of (a) theoretical analysis, experimentation, or systematic study of phenomena or observable facts, (b) the development or testing of basic engineering techniques, (c) the extension of investigative findings or theory of a scientific or technical nature into practical application for experimental and demonstration purposes… (d) the collection, exchange, and analysis of research information, or (e) any combination of the [above]." RJV members can be from different sectors as well as from different countries.

[35]These points are taken from Vonortas (1997); however, Vonortas credits these ideas to Douglas (1990).

Figure 2-25.
Growth in R&D consortia registered under the National Cooperative Research and Production Act



SOURCE: Link (1999) and unpublished tabulations.

Science & Engineering Indicators – 2000

Other observations include:

- The industry with the most RJVs over the 1985–98 period was communication services (standard industrial classification, or "SIC," number 48), which claimed 131 of the 741 total. The electronics industry (SIC 36) was a close second with 120, followed by transportation equipment (SIC 37) with 115.
- The average number of members per RJV over the 1985–98 period was 13; this number varied by industry, however, from an average of only 6 members for the communications services industry to an average of 25 for the electronics industry.
- Only 10 percent of all RJVs included Federal laboratories as research members. Among RJVs in the communications services industries, less than 1 percent had Federal labs as members. Among those in machinery and computer equipment (SIC 35), 21 percent included Federal labs; among those in electronics, 20 percent included Federal labs.
- Sixteen percent of all RJVs included universities as research members. For communications services, this percentage was as low as 5, whereas for electronics it was as high as 34.
- As many as 29 percent of all RJVs had foreign affiliates as research members, ranging from 17 percent for transportation equipment to 45 percent for the oil and gas extraction industry (SIC 13).
- Fourteen percent of RJVs had an environmental research focus; no RJVs in communications services had an environmental research focus, whereas 43 percent in chemicals and allied products (SIC 28) had that focus.
- Forty-nine percent of RJVs (365 of the 741 total) had research that was process-focused; 41 percent (307) had research that was product-focused; and the remaining 9 percent (69) had research that included both. (See figure 2-25.)

International Comparisons of National R&D Trends

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities and are a harbinger of future growth and productivity. Indeed, investments in the R&D enterprise strengthen the technological base on which economic prosperity increasingly depends worldwide. Findings from a study of 25 countries by Porter and Stern (1999) indicate that human talent and R&D spending are among the most important factors contributing to nations' innovative capacity. Consequently, the relative strength of a particular country's current and future economy—and the specific scientific and technological areas in which a country excels—is further revealed through comparison with other major R&D-performing countries. This section provides such comparisons of international R&D spending patterns.[36] It examines absolute and relative expenditure trends, contrasts performer and source structural patterns, reviews the foci of R&D activities, and looks at government priorities and policies. Although R&D performance patterns by sector are similar across countries, national sources of support differ considerably. In nearly all OECD countries, government has provided a declining share of all R&D funding during the past decade, whereas the industrial share of the funding total has increased considerably. Foreign sources of R&D have been increasing in many countries.

Absolute Levels of Total R&D Expenditures

The worldwide distribution of R&D performance is concentrated in relatively few industrialized nations. Of the $500 billion in estimated 1997 R&D expenditures for the 28 OECD[37] countries, 85 percent is expended in just 7 countries (OECD 1999d). These estimates are based on reported R&D investments (for defense and civilian projects) converted to U.S. dollars with purchasing power parity (PPP) exchange rates.[38] (See appendix table 2-2.)

[36]Most of the R&D data presented here are from reports to OECD, which is the most reliable source of such international comparisons. A fairly high degree of consistency characterizes the R&D data reported by OECD, with differences in reporting practices among countries affecting their R&D/GDP ratios by no more than an estimated 0.1 percentage point (ISPF 1993). Nonetheless, an increasing number of non-OECD countries and organizations now collect and publish internationally comparable R&D statistics, which are reported at various points in this chapter.

[37]Current OECD members are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[38]Although PPPs technically are not equivalent to R&D exchange rates, they better reflect differences in countries' laboratory costs than do market exchange rates. (See sidebar, "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data.")